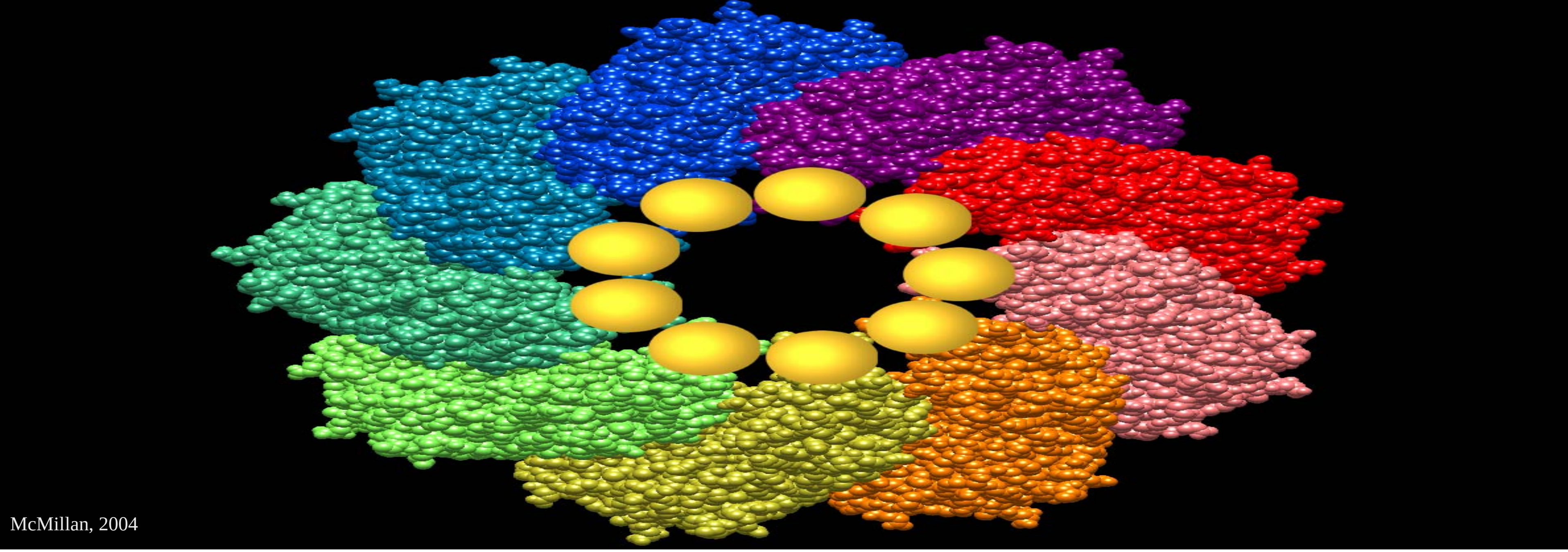


Transforming and Responsible Nanotechnology Research and Development

Dr. M.C. Roco

Chair, U.S. Nanoscale Science, Engineering and Technology (NSET), NSTC
Senior Advisor for Nanotechnology, National Science Foundation

Presentation posted on **www.nsf.gov/nano**

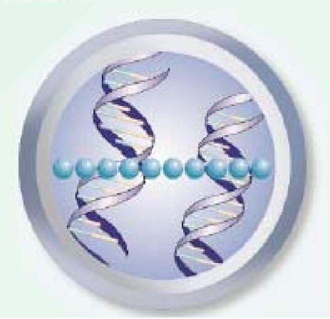
San Francisco, November 8, 2004

Nanotechnology development cannot be decided only by nanotechnologists

Nanotechnology will broadly affect society, from new products to art

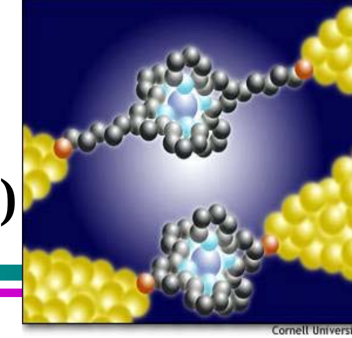
Topics

- **National Nanotechnology Initiative - a transforming program**
- **Major changes in the first four years - setting new goals in 2004**
- **Societal implications: immediate and long term issues**
- **The international context**



Nanotechnology

Definition on www.nano.gov/omb_nifty50.htm (2000)



- **Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure**

- **NNI definition encourages new contributions that were not possible before**

  - novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain

  - the ability to measure / control / manipulate matter at the nanoscale in order to change those properties and functions

  - integration along length scales, and fields of application

Chances and risks of technology

- **Human potential and technological development are coevolving, and quality of life has increased with technological advancements**

  However, there is a perceived tension between the society and technology (maybe because significant changes, accelerated path, larger benefits & risks)

- **Technology implications are global issues (human development, EHS) that need to be addressed together**

  NNI – promotes multidomain approach, interagency and international collaborations

TRANSFORMING SOCIETAL IMPLICATIONS
(Ex: worldwide estimations made in 2000, NSF)

- **Knowledge base**: better comprehension of nature, life
- **New technologies and products: ~ $1 trillion/year by 2015**
  (With input from industry US, Japan, Europe 1997-2000, access to leading experts)

  Materials beyond chemistry: $340B/y
  Pharmaceuticals: $180 B/y
  Aerospace about $70B/y
  Electronics: over $300B/y
  Chemicals (catalysts): $100B/y
  Tools ~ $22 B/y

  Est. in 2000 (NSF) : about $40B for catalysts, GMR, materials, etc.; + 25%/yr
  Est. in 2002 (DB) : about $116B for materials, pharmaceuticals and chemicals

  Would require worldwide ~ 2 million nanotech workers

- **Improved healthcare**: extend life-span, its quality, physical capabilities
- **Sustainability**: agriculture, food, water, energy, materials, environment; ex: lighting energy reduction ~ 10% or **$100B/y**

UNINTENDED SOCIETAL IMPLICATIONS:
Secondary consequences and risks
(sample of issues)

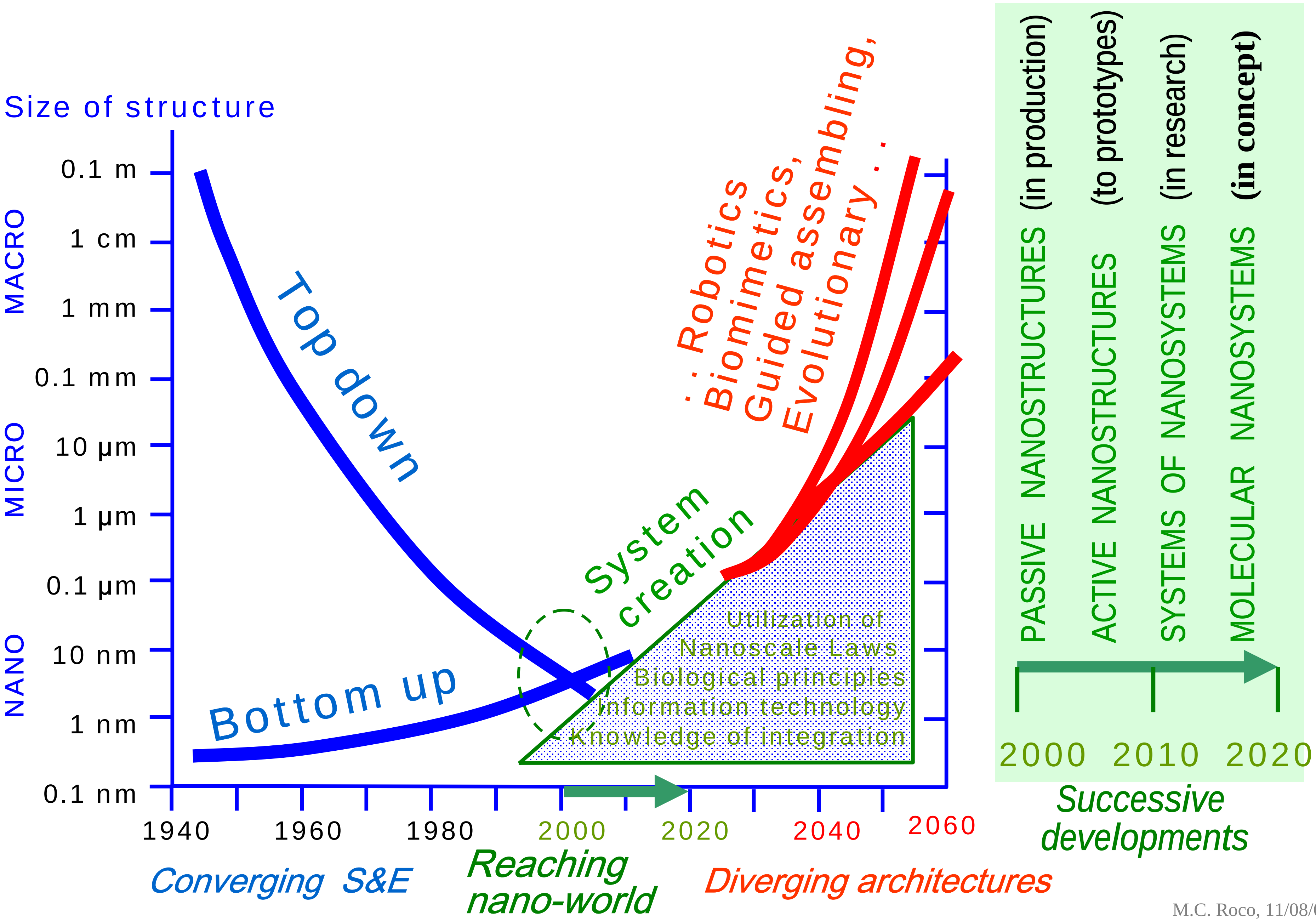
- **Knowledge base**: creation of organisms? philosophical issues?
- **New technologies and products**: industry restructuring?

  Materials beyond chemistry: new material properties? safety?
  Electronics: society as an interconnected brain? privacy?
  Pharmaceuticals: secondary effects of medication? behavior control?
  Quality of life? New chemical manufacturing methods? . . . . .

  Changing jobs and organizations. Nano-divide?

- **Improved healthcare**: ethical and social issues? human dignity?
- **Sustainability**: impact of nanostructures on environment? cleaning existing contaminants? What is the new population limit for sustainable development with nanotechnology?

Reaching nano-world and system creation



M.C. Roco, 11/08/04

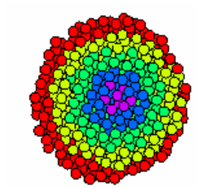
10-20 years vision

Timeline for beginning of industrial prototyping and commercialization

Increased integration, system approach

Converging science and engineering

- **1st Generation:** Passive nanostructures **~ 2000**



Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics - *R&D and FIRST PRODUCTS*

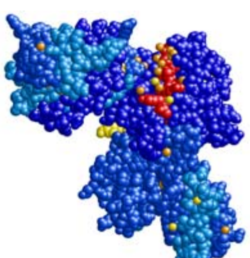
- **2nd Generation:** Active nanostructures **~ 2005**

Ex: transistors, amplifiers, targeted drugs, actuators, adaptive structures - *R&D ONLY*

- **3rd Generation:** Systems of nanosystems **~ 2010**

Ex: guided molecular assembling; 3D networking and new system architectures, robotics, supramolecular

- **4th Generation:** Molecular nanosystems **~ 2020**



Ex: molecules as devices/components 'by design', based on atomic design, hierarchical emerging functions, evolutionary systems

AIChE Journal, 2004, Vol. 50 (5), MC Roco

R&D towards the Next Industrial Revolution

1999 metrics, 2004 check the progress, 2015 to satisfy first criteria

Systematic control matter on the nanoscale will lead to the next industrial revolution

- **Changing the foundation of understanding, control, manufacturing and medicine from the macro and micro domains to the nanoscale, where all fundamental material properties and functions can be efficiently established and changed**

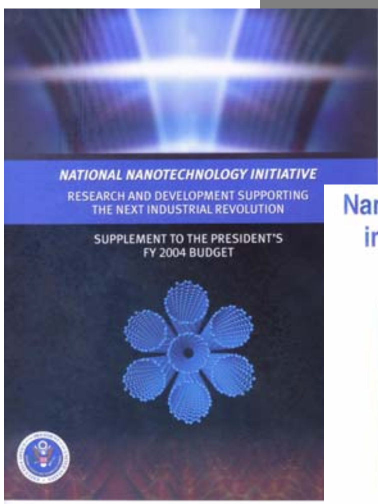
- **General purpose technology that will affect almost all sectors of the society. It will disrupt - structural changes - markets, industrial organizations and business models (ex: 50% of new products in advanced industrial areas will use NS&E by 2015)**

Defining the vision (II)

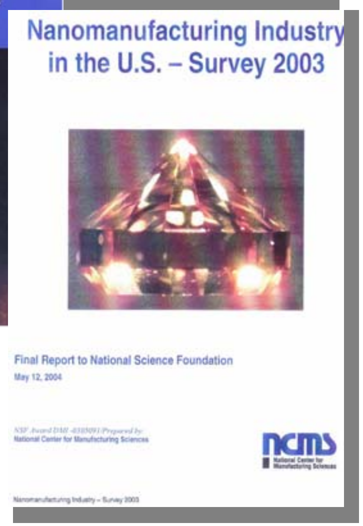
National Nanotechnology Initiative

2004

2004:
10-year
vision

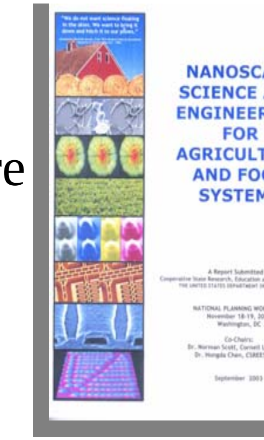


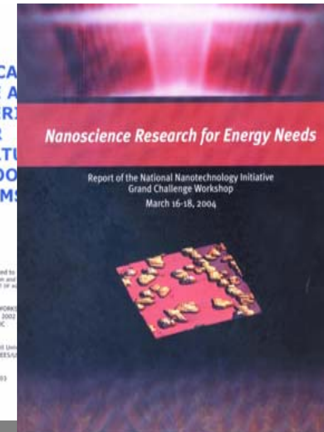
Government
Plan (annual)



Survey
manufacturing

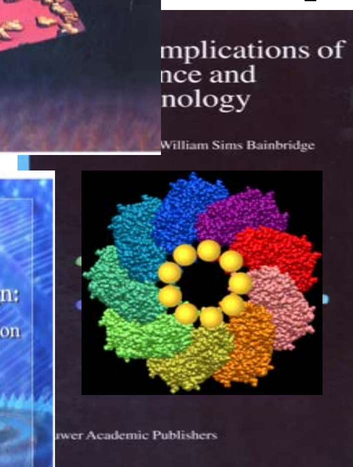
Agriculture
and Food



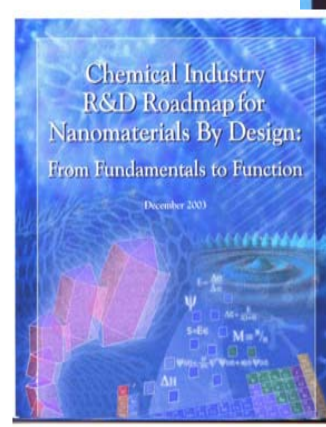


Energy

Societal
Implications
2004

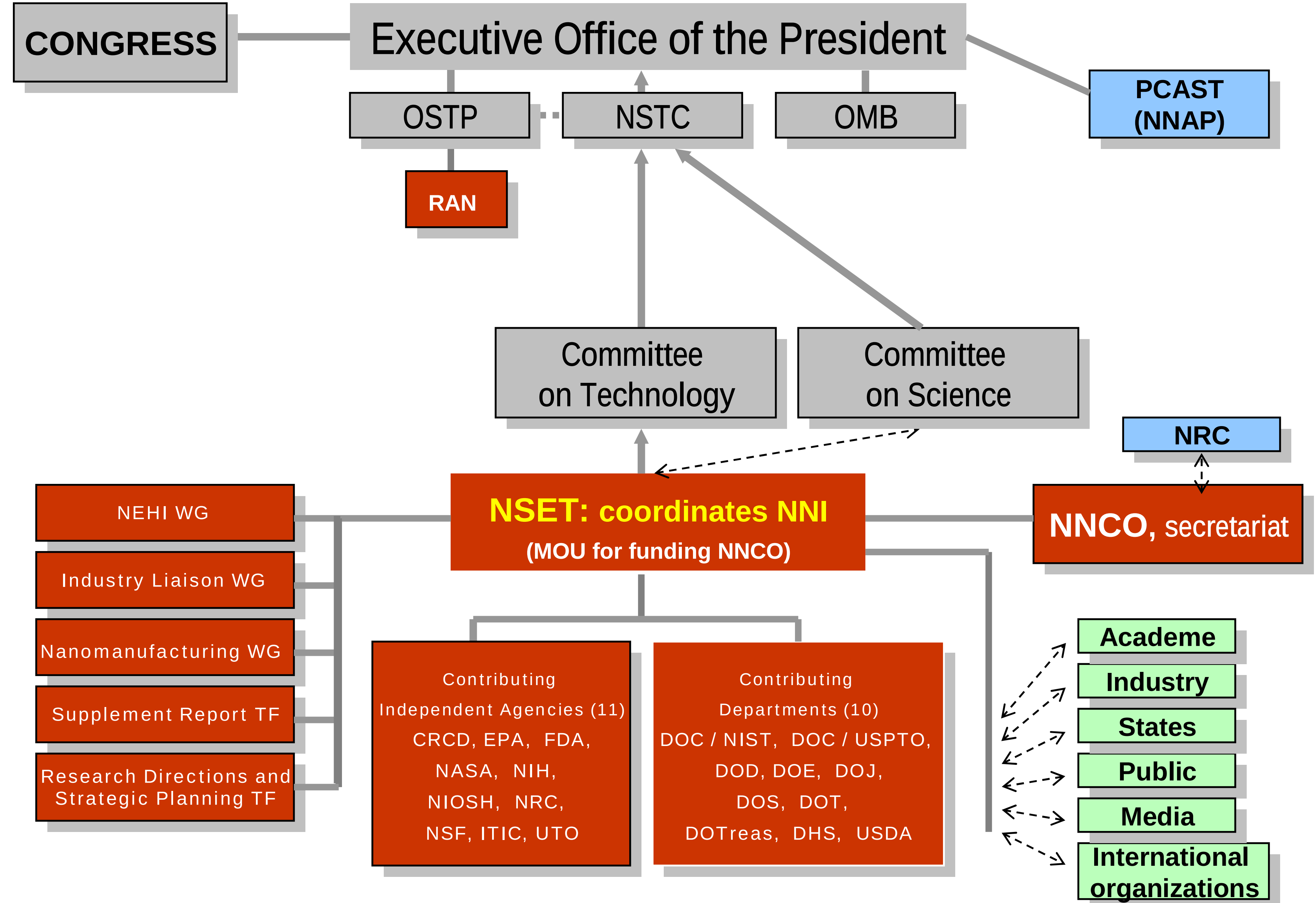


Reports



Other topical reports
on www.nano.gov

2004: Update 10 year vision, and develop strategic plan



Organization chart of the NNI

Grey: supervising organizations; Red: organizations implementing NNI; Blue: organizations evaluating NNI; Dash lines: infromational links

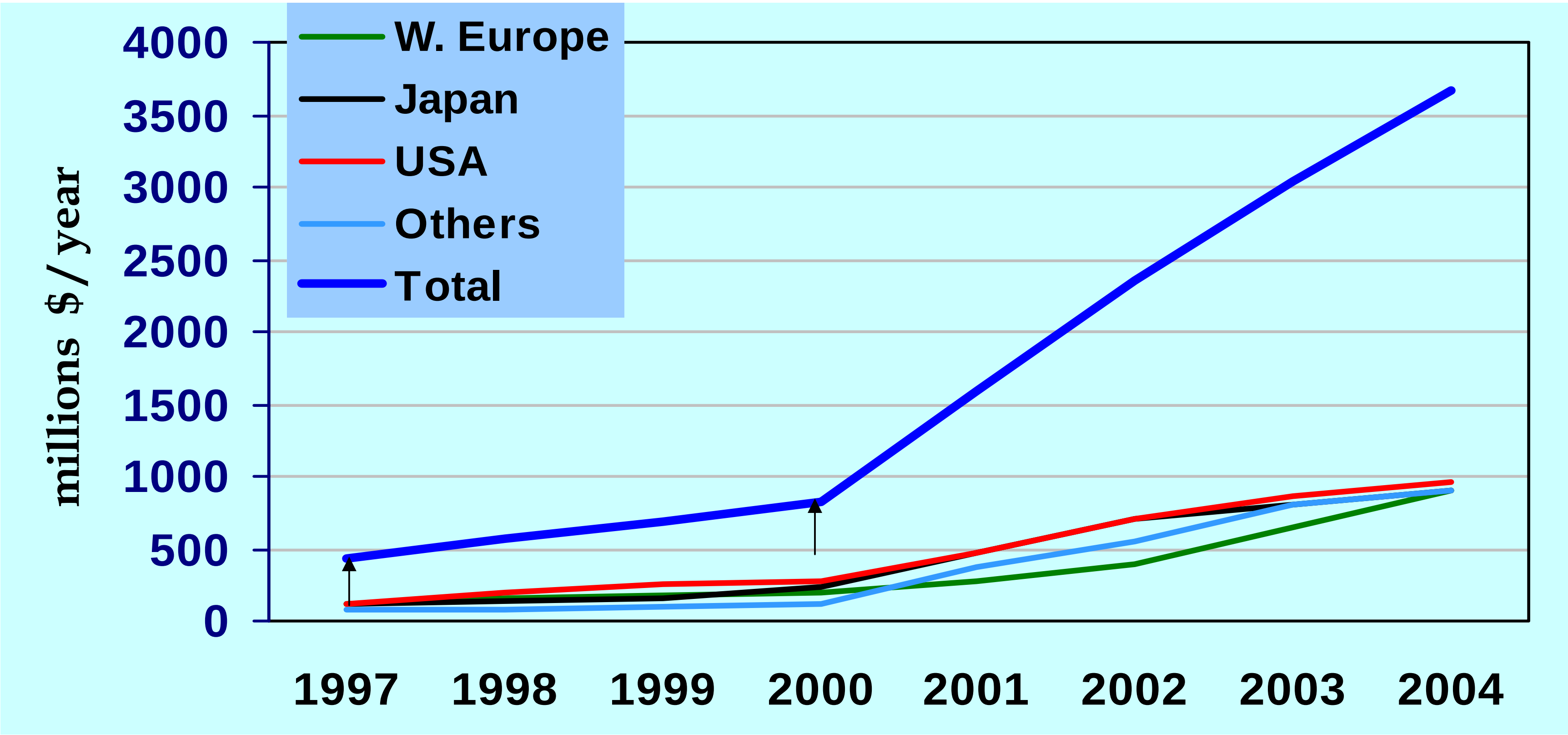
NNI: R&D Funding by Agency

Fiscal year (all in million $)	*2000* Actual	*2001* Enact/Actual	*2002* Enact/Actual	*2003* Enact/Actual	2004 Req./ Enact	2005 Req
National Science Foundation	97	150 /150	199 /204	221 /221	249 /254	305
Department of Defense	70	110 /125	180 /224	243 /322	222 /315	276
Department of Energy	58	93 /88	91.1 /89	133 /134	197 /203	211
National Institutes of Health	32	39 /39.6	40.8 /59	65 /78	70 /80	89
NASA	5	20 /22	35 /35	33 /36	31 /37	35
NIST	8	10 /33.4	37.6 /77	66 /64	62 /63	53
EPA	-	/5.8	5 /6	5 /5	5 /5	5
Homeland Security (TSA)	-		2 /2	2 /1	2 /1	1
Department of Agriculture	-	/1.5	1.5 /0	1 /1	10 /1	5
Department of Justice	-	/1.4	1.4 /1	1.4 /1	1.4 /1	1
TOTAL	270	422 /465	600 /697	770 /862	849 /961	982
		+72%	+50%	+24%		

- Industry, state and local organizations: about 1.5 times NNI budget in 2003
- 21 NSET departments / agencies, including: OSTP, NSTC, OMB, DOC, DOS, DOT, DOTreas, FDA, NRC, DHS, IC, NIOSH, USPTO; partnerships with others
- NNI budget: 65% to academia; 25% - R&D labs; 10% - industry (7% SBIR)

Context – Nanotechnology in the World

Past government investments 1997-2004 (est. NSF)



Note:

- U.S. begins FY in October, six months in advance of EU & Japan (in March/April)

NNI implementation plan published in July 2000

Major changes in the first 3 years of NNI (Part 1)

- **Research:** NNI supports about 2,500 active awards in about 300 academic organizations and 200 private organizations in all 50 states; Developments faster than expected: Reducing the time of reaching commercial prototypes by at least of factor of two for several key applications. Half of world HI papers. Setting new goals.

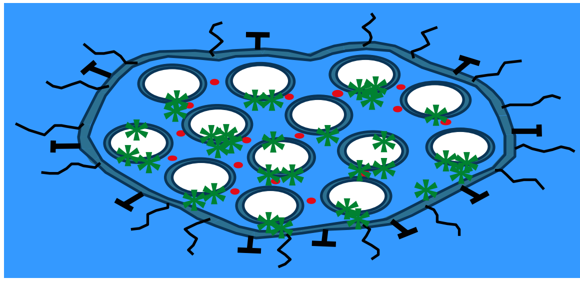
- **Education**: 7,000 students and teachers trained in 2003; All science and engineering colleges have introduced courses related to NSE.   Earlier nanotechnology education.

- **Significant infrastructure:** in over 60 universities with user capabilities; Five networks (NCN,NNIN, OKN, DOE, NASA) have been established. About 40,000 workers

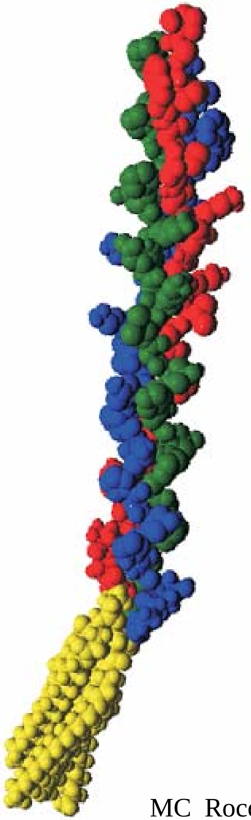
Example:

Synthesis and control of nanomachines

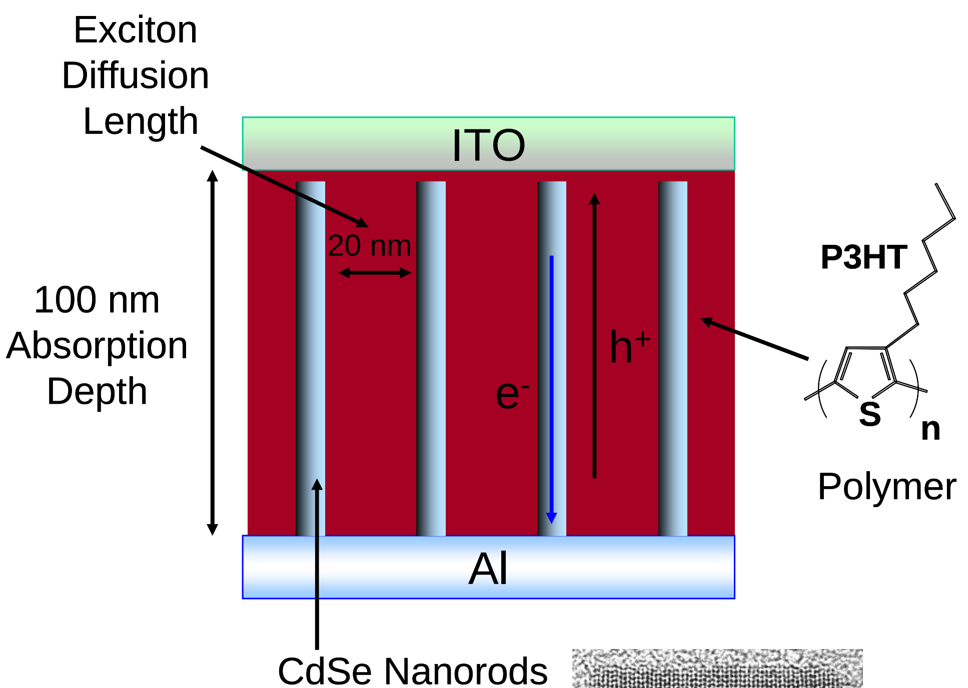
(examples NSE in 2004, www.nseresearch.org - 250 projects)

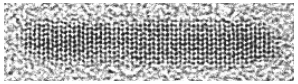


- **Self-assembly processing** of nanoscale bio-materials and devices for micromachines components (UCSB)
- Chemistry to synthesize components of **nano machines to work on surfaces** and be activated by external electromagnetic fields (UCB)
- **Light driven molecular motors** (U. Nevada)
- **Combinatorial engineering of nanomachines**, with application to membranes and filters (U. Penn.)
- **Nanoengineering surfaces** for probing viral adhesion (UC Davis)



Energy: Schematic design of the nanorod-polymer solar cell



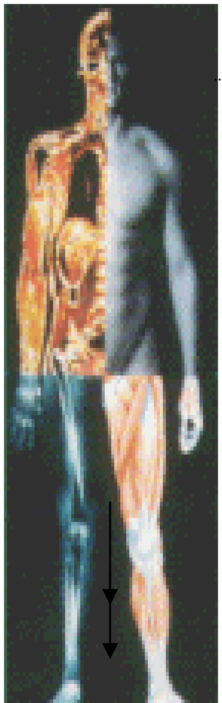


transmission electron micrograph of a CdSe nanorod at the bottom

(courtesy P. Alivisatos, Univ. California, Berkeley; and Nanosys, Inc.).

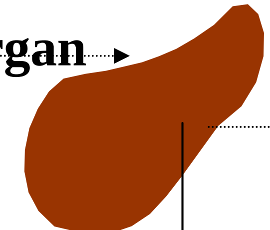
Examples of levels for intervention of nanobiotechnology
in human life extension

Human



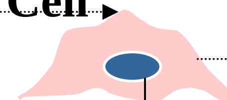
- Joint replacement
- Non-invasive and invasive diagnostics for rapid patient monitoring
- Cognitive-assist devices
- Targeted cancer therapies

Organ



- Artificial organs
- Sensors for in vivo monitoring
- Localized drug delivery
- Neural stimulation
- Cardiac therapies

Cell



- Improved cell-material interactions
- Scaffolds for tissue eng.
- Genetic therapies
- Cell ageing
- Stem cell therapies

Molecule

- Localized drug delivery
- Gene therapy devices
- Self-assembly structures
- Fast diagnostic techniques

(NBIC Report, 2002)

Exponential growth; About half of the highly cited papers in key journals originate in U.S.

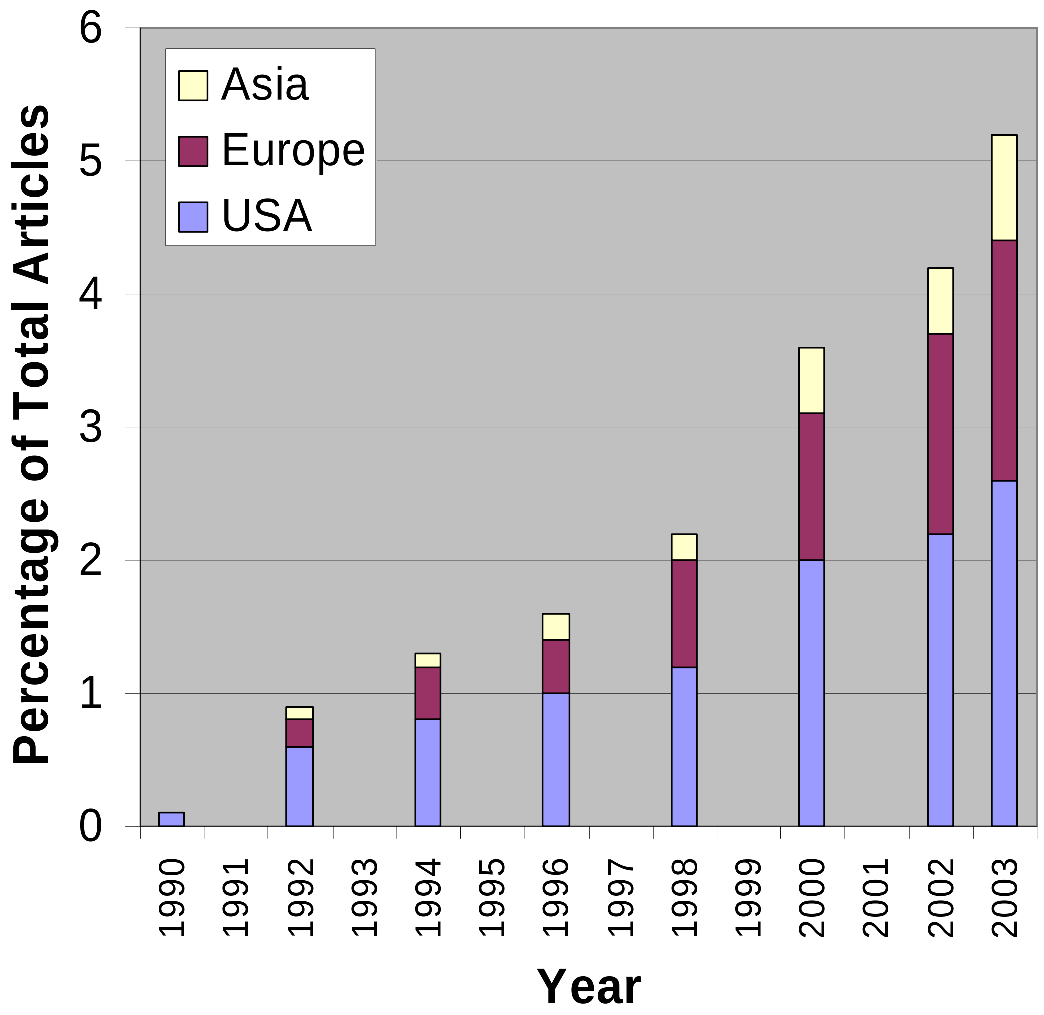
("nano*" keyword search, after NNI Report, 2005)

Journal ISI with high Impact Factors (2001):

Nature	27.9
Science	23.3
Physics Review Letters	6.6

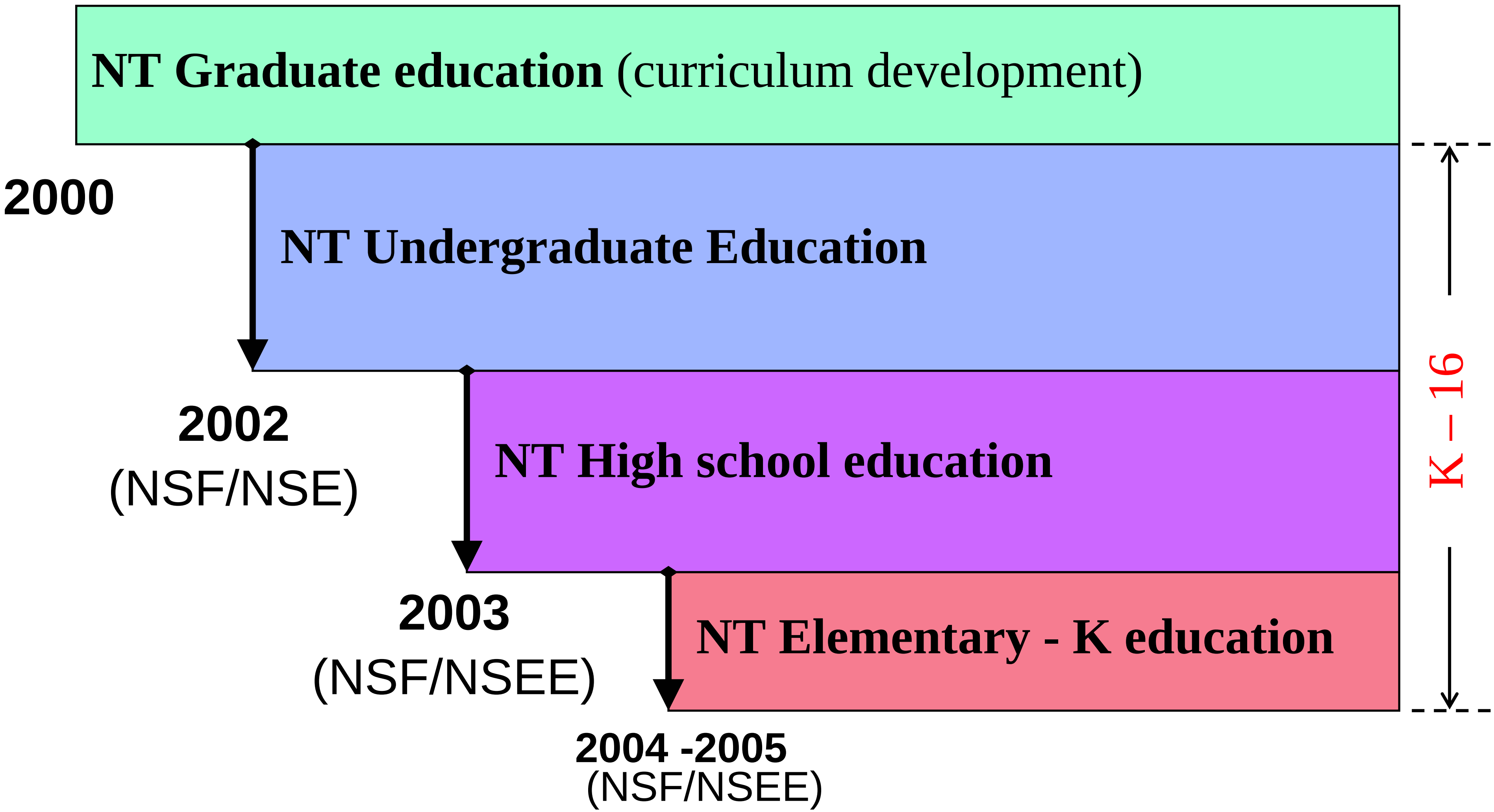
All others journals have impact factors under 4

Correlates well with the overall papers with ISI high impact



MC Roco, 11/08/04

Introducing earlier nanotechnology education
(NSF: Nanoscale Science and Engineering Education)



Infrastructure 2001-2004: 33 R&D Centers, Networks and User Facilities

Funded by NSF (21), DOD (3), NASA (4), and DOE (5)

2000

- Nanobiotechnology, Cornell (STC)
- Network for Computational Nanotechnology (7)
- Oklahoma Nano Net

2001

- Nanoscale Systems in Information Technologies (NSEC)
- Nanoscience in Biological and Env. Eng. (NSEC)
- Integrated Nanopatterning and Detection (NSEC)
- Electronic Transport in Molecular Nanostructures (NSEC)
- Nanoscale Systems and their Device Applications (NSEC)
- Directed Assembly of Nanostructures (NSEC)

- Institute for Soldier Nanotechnology (UARC)
- Nanoscience Innovation for Defense, MIT
- Nanoscience Institut, NRL

2002

- MRSECs on nanostructures

- Institute for Cell Mimetic Space Exploration
- Institute for Intelligent Bio-Nanomaterials & Structures for Aerospace Vehicles
- Bio-Inspection, Design, and Processing of Multi-functional Nanocomposites
- Institute for Nanoelectronics and Computing

2003

- Integrated and Scalable Nanomanufacturing (NSEC)
- Nanoscale Chem., Electr., and Mech. Manu. Systems (NSEC)
- Extreme Ultraviolet Science and Technology (ERC)
- National Nanotechnology Infrastructure Network (13)

2004

- Integrated Nanomechanical Systems (NSEC)
- High Rate Nanomanufacturing (NSEC)
- Affordable Nanoeng. of Polymer Biomedical Devices (NSEC)
- Nano/Bio Interface (NSEC)
- Probing the Nanoscale (NSEC)
- Templated Synthesis and Assembly at the Nanoscale (NSEC)
- Nanotechnology Center for Learning and Teaching (10)

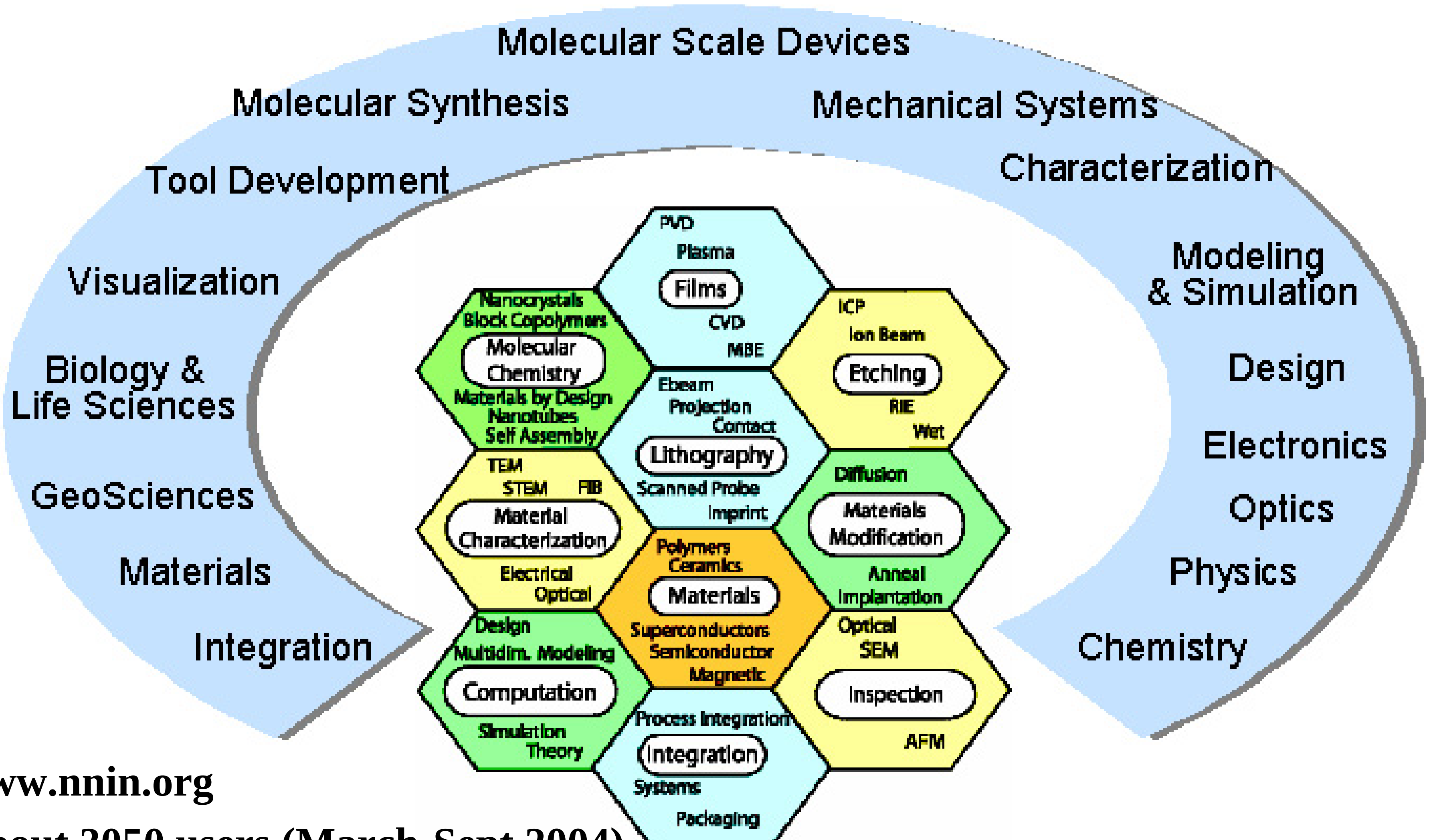
Operation 2005-2007

- Molecular Foundry
- Center for Integrated Nanotechnologies
- Center for Nanophase Materials Sciences
- Center for Nanoscale Materials
- Center for Functional Nanomaterials

2005

MC Roco, 11/08/04

NSF NNIN Scope and Activities
(13 nodes, lead Cornell University)

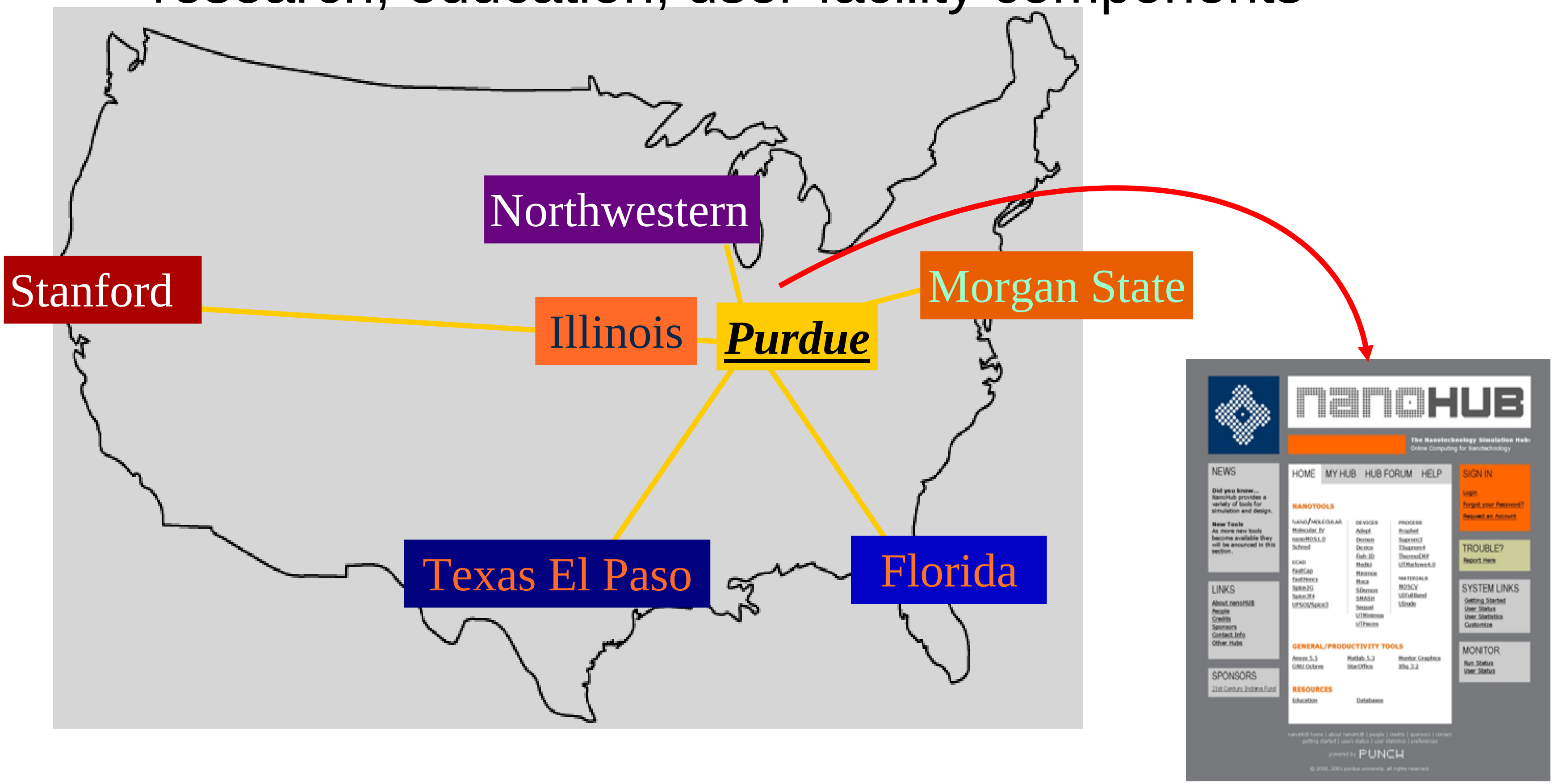


www.nnin.org

About 3050 users (March-Sept 2004)

Network for Computational Nanotechnology (7 nodes, lead Purdue University)

Multi-scale, multi-disciplinary from “atoms to systems” research, education, user-facility components



www.nanohub.purdue.edu ; About 3,000 users in FY 2004

DOE Nanoscale Science Research Centers

Summer '03

Center For Nanophase Materials Sciences at ORNL

Spring '05

Center For Functional Nanomaterials at BNL

Spring '04

Molecular Foundry at LBNL

Spring '04

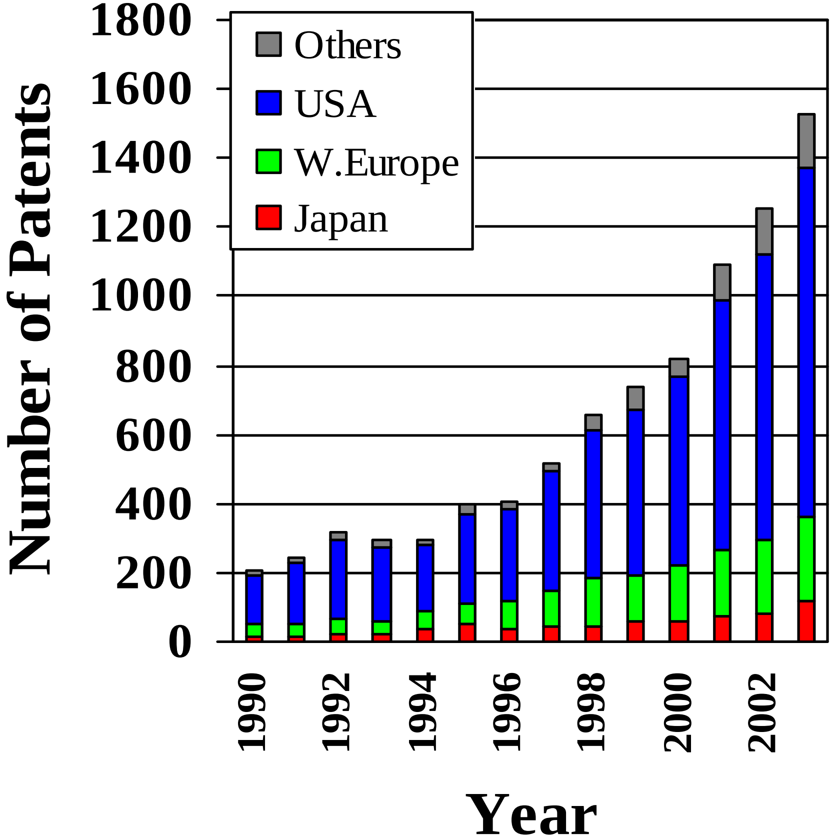
Center for Nanoscale Materials at Argonne

Center for Integrated Nanotechnologies

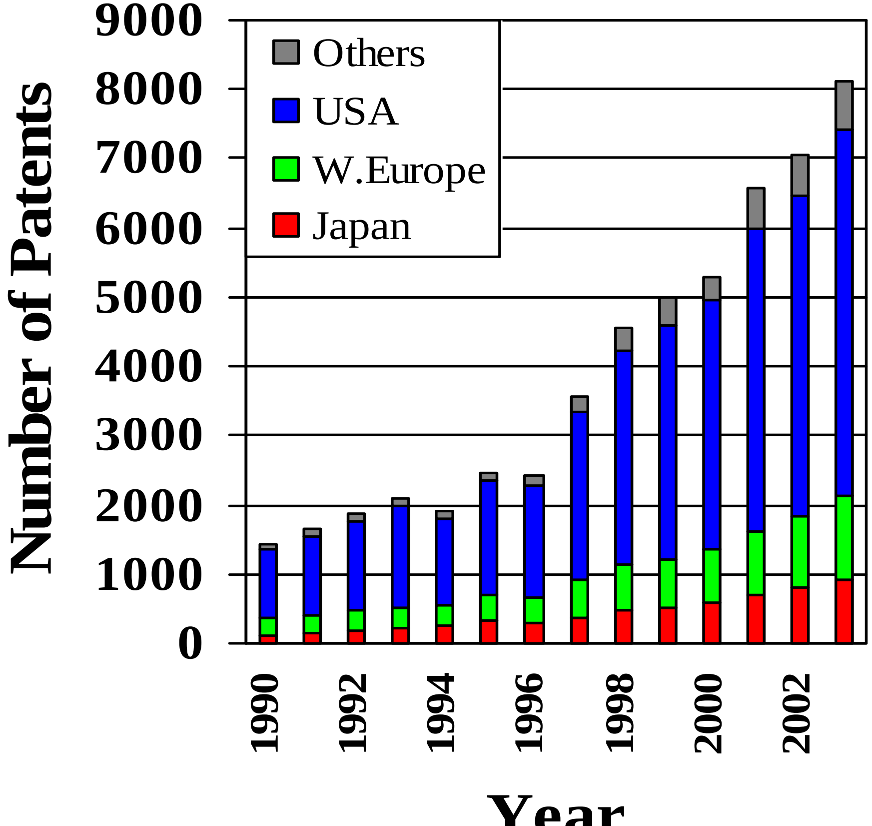
Exponential growth (USPTO database)

using "Title-claims"and "Full-text" search for nanotechnology by keywords
(using intelligent search engine, after J. Nanoparticle Research, 2004, Vol. 6, Issue 4)

"Title-claims" search:
nanotechnology claims



"Full-text" search:
nanotechnology claims, or/and NSE tools and methods



MC Roco, 11/08/04

NNI-Industry Consultative Boards for Advancing Nanotech

Key for development of nanotechnology, Reciprocal gains

- **NNI-Electronic Industry (SRC lead), October 2003**
  - Collaborative activities in key R&D areas
  - 5 working groups, Periodical joint actions and reports
  - NSF-SRC agreement for joint funding; other joint funding
- **NNI-Chemical Industry (CCR lead)**
  - **Joint road map for nanomaterials R&D**
  - **2 working groups, including on EHS**
  - **Use of NNI R&D results, and identify R&D opportunities**
- **NNI – Organizations and business (IRI lead)**
  - **Joint activities in R&D technology management**
  - **2 working groups (nanotech in industry, EHS)**
  - **Exchange information, use NNI results, support new topics**
- **In developments: NNI - Pharmaceuticals (Phrma lead)**
  NNI - Automotive industry

Industry surveys

- Companies working in nanotechnology

Survey by Small Times in 2004, based on individual contacts and direct verification:

875 nanotech companies

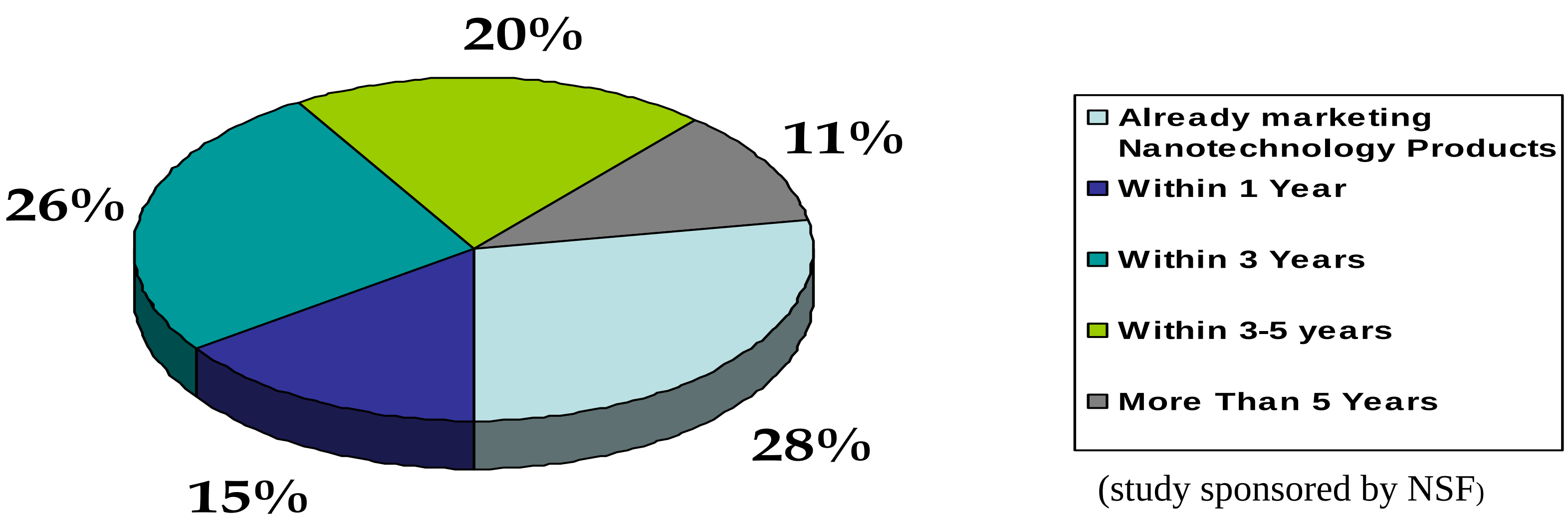
475 products in 215 companies

- Timeline for commercialization

Survey by National Center for Manufacturing Sciences:

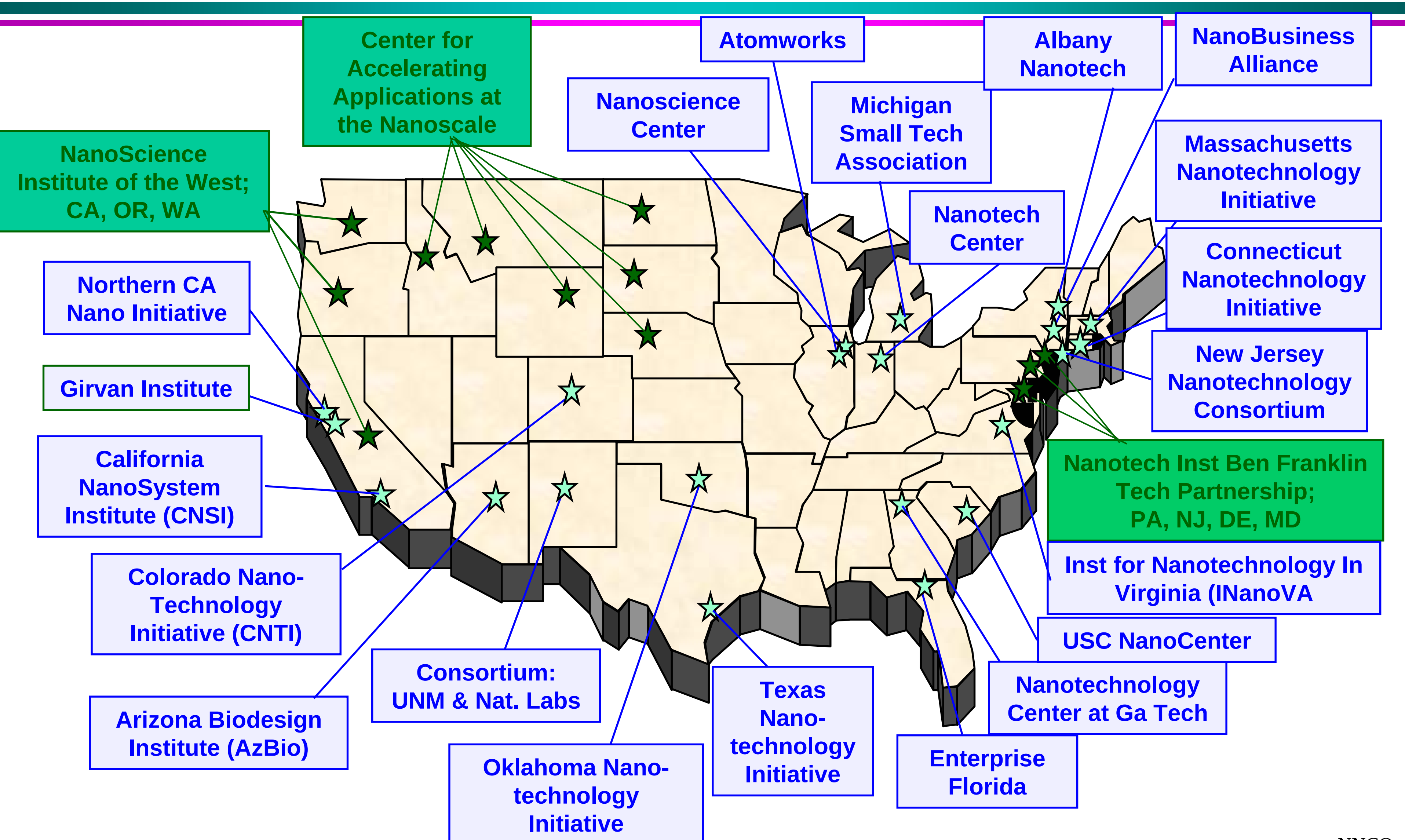
81 manufacturing companies:

89% expect products in less than 5 years

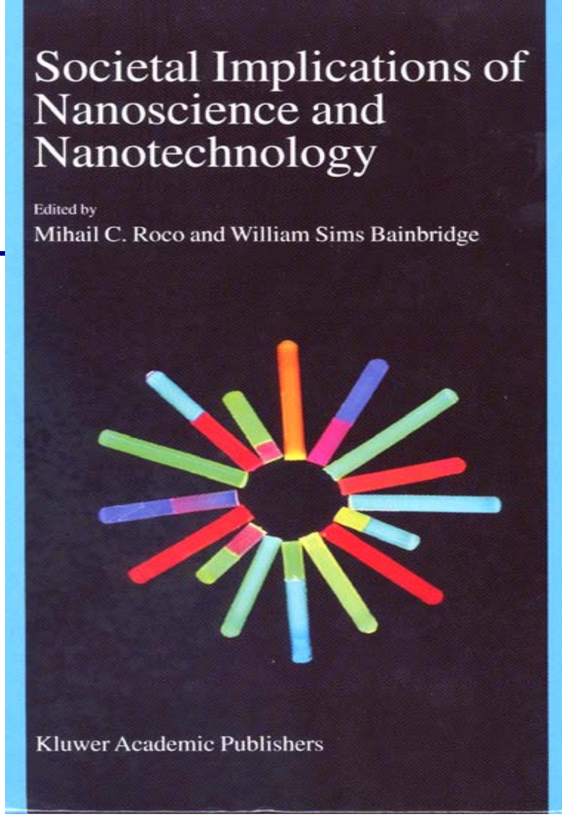


(study sponsored by NSF)

Sampling of Current Regional, State, & Local Initiatives in Nanotechnology



Societal Implications: Follow-up of the September 2000 report



http://nano.gov

- Make support for social, ethical, and economic research studies a priority:
  (a) New theme in the NSF program solicitations;
  (b) Centers with societal implications programs;
  (c) Initiative on the impact of technology, NBIC, HSD
- NNCO – communicate with the public and address Environmental, Health and and Safety issues, and unexpected consequences
- NSET's Nanostructures Environmental and Health Issues working group has been established in 8/2003, 12 agencies
- Workshop with EC (2001); Links to Europe, Americas, Asia; International Dialogue (26 countries, NSF-sponsored)

Key issues in long term

- Respect human right to: access to knowledge and welfare; human integrity, dignity, health and safety
- Balanced and equitable R&D nanotechnology investment
- Environment protection and improvement (water, air, soil) Sustainable development, life-cycle of products, global effects (weather), eliminate pollution at the source
- Economic, legal, ethical, moral, regulatory, social and international (developed-developing countries) aspects Interacting with the public and organizations
- Adaptive/corrective approach for a complex system

Immediate and continuing issues:

- *EHS in research laboratories and industrial units*
- *Harmonizing nomenclatures, norms and standards*
- *Primary data and methodology for risk analysis*

NNI activities

for Environmental, Health and other Societal Implications

A. Align R&D investment with societal implications

B. Evaluate and implement regulatory standards

C. Coordinated measures for EHS and ELES

D. Periodical meeting for grantees,
setting research targets, and
interaction with industry and the public

E. International collaboration (International Dialog
for Responsible R&D of Nanotechnology)

A. NNI coordination for R&D investments

- NSF research grants on environmental and societal implications
  All basic R&D areas, transport of nanoparticles; Programs since 2000
- NIH research on effects of nanoscale materials in the body
- EPA research grants on environmental implications of manufactured nanomaterials
- National Toxicology Program (NIEHS, NCTR, NIOSH)
  Project to study toxicity of nanotubes, quantum dots, and titanium dioxide
- NIST development of standards and measurements for nanoscale particles
- FDA and USPTO training and specialized activities
- USDA and DOE support fate and transport studies
- DOD supports exposure studies
- Solicitations (SI): NSF (ENV, SI), EPA-NSF-NIOSH, USDA, NIH

Investment in societal (ethical, economic, etc.), educational and environmental implications

Increased NNI investments are planned, because of (a) creation of new nanostructures and advancing knowledge; (b) nanotechnology products move to the market; and (c) growth of interdisciplinary societal implication research

a. For societal and educational implications

(Cross-cutting, including contributions from student fellowships).

FY 2004 ~ $45M NSF ($37M+$3M = $40M), DOD ($2M), NIH ($2M), NASA ($1.2M), NIST, EPA

Note: <u>$45M</u> is ~ 4-5% of $960M

b. For nanoscale R&D with relevance to environment/health/safety

(Crosscutting, including env. processes, benign nano-manufacturing, implications)

FY 2004 ~ $95M NSF ($41M), NIH ($33M), EPA ($5M), DOE, USDA, NIST, NASA, NIOSH, FDA

(It includes relevant basics and implications)

Note: <u>$95M</u> is ~ 10% of $960M

($142M including +$47M for NIH health applications)

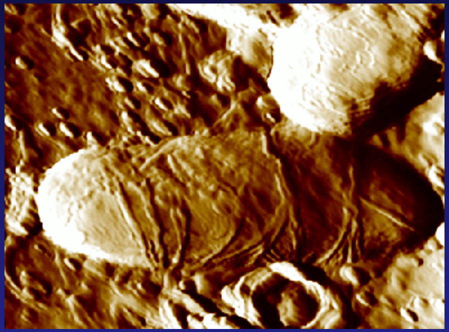
NSF environmental centers and interdisciplinary groups with research and education at the nanoscale

Center (details on www.nsf.gov/home/crssprgm/nano/nni01_03_env.htm)	**Institution**
Fundamental Studies of Nanoparticles Formation in Air Pollution	Worcester Polytechnic Institute ($2.7M)
Center for Advanced Materials for Water Purification	University of Illinois at Urbana ($20.1M)
Center for Environmentally Responsible Solvents and Processes	University of North Carolina at Chapel Hill ($25.0M)
Nanoscience in Biological and Environmental Engineering (estimated 50% in environment)	Rice University ($11.8M)
Environmental Molecular Science Institute	Univ. of Notre Dame ($5M)
NIRT: Investigating Nano-carbon Particles in the Atmosphere: Formation and Transformation	University of Utah ($1.7M)
NIRT: Nanoscale Processes in the Environment - Atmospheric Nanoparticles	Harvard University ($1.6M)
Center for Advanced Computational Environment	SUNY Buffalo ($5.5M)
NIRT: Nanoscale Sensing Device for Measuring the Supply of Iron to Phytoplankton in Marine Systems	University of Maine ($0.9M)

Environmental Molecular Science Institute

Jeremy Fein, University of Notre Dame

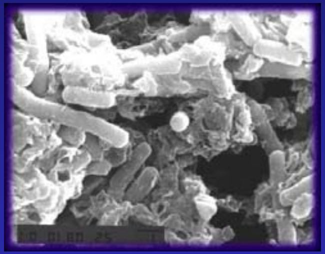
Funding: NSF, DOE



Science/Engineering Projects

Mission**:** Determine the effects of nano- and micro-particles on heavy metal and radionuclide transport in geologic systems.

-Bacteria
-Natural Organic Matter
-Nanoscale Mineral Aggregates



Education/Outreach Projects

- REU Summer Program
- High School Student Internships
- Active Recruitment of Under-represented Groups with G.E.M.
- National Lab/Industry Internships

National Lab/Industry Partnerships

- Argonne (APS; Actinide Facility)
- Sandia (molecular dynamics modeling)
- Oak Ridge (geomicrobiology)
- DuPont Engineering Technologies

NNI projects supporting toxicity research (examples)

Project	Agency, Institution
National Toxicology Program ($0.5M in FY 2004 to $5M in FY 2008)	NIH/NIEHS, FDA/NCTR, NIOSH
Particle characterization for health and safety ($1.7M in FY 2004 rto $2.3M in FY 2005)	NIOSH
Nanotechnology Characterization Laboratory ($5M/yr, part of $144M/yr NCI for FYs 2004-2008)	National Cancer Institute
Multidisciplinary University Research on Nanoparticle Toxicity	Department of Defense supported center
Molecular function at the Nano-Bio Interface (component on nanostructures and cell behavior)	NSF/NSEC U. Pennsylvania
Nanomanufacturing Center for Enabling Tools (component on safe manufacturing)	NSF/NSEC Northeastern University
Size Dependent Neural Translocation of Nanoparticles	NSF/SGER, Rochester University
Reverse Engineering Cellular Pathways from Human Cells Exposed to Nanomaterials	NSF/SGER

National Toxicology Program organization

NTP Director
Dr. K. Olden,
Dir NIEHS

Policy Oversight

Executive Committee

ATSDR	NCI/NIH
CPSC	NIEHS/NIH
EPA	OD/NIH
FDA	NIOSH/CDC
NCEH/CDC	OSHA

Environmental Toxicology Program

External Science Oversight and Peer Review

Board of Scientific Counselors

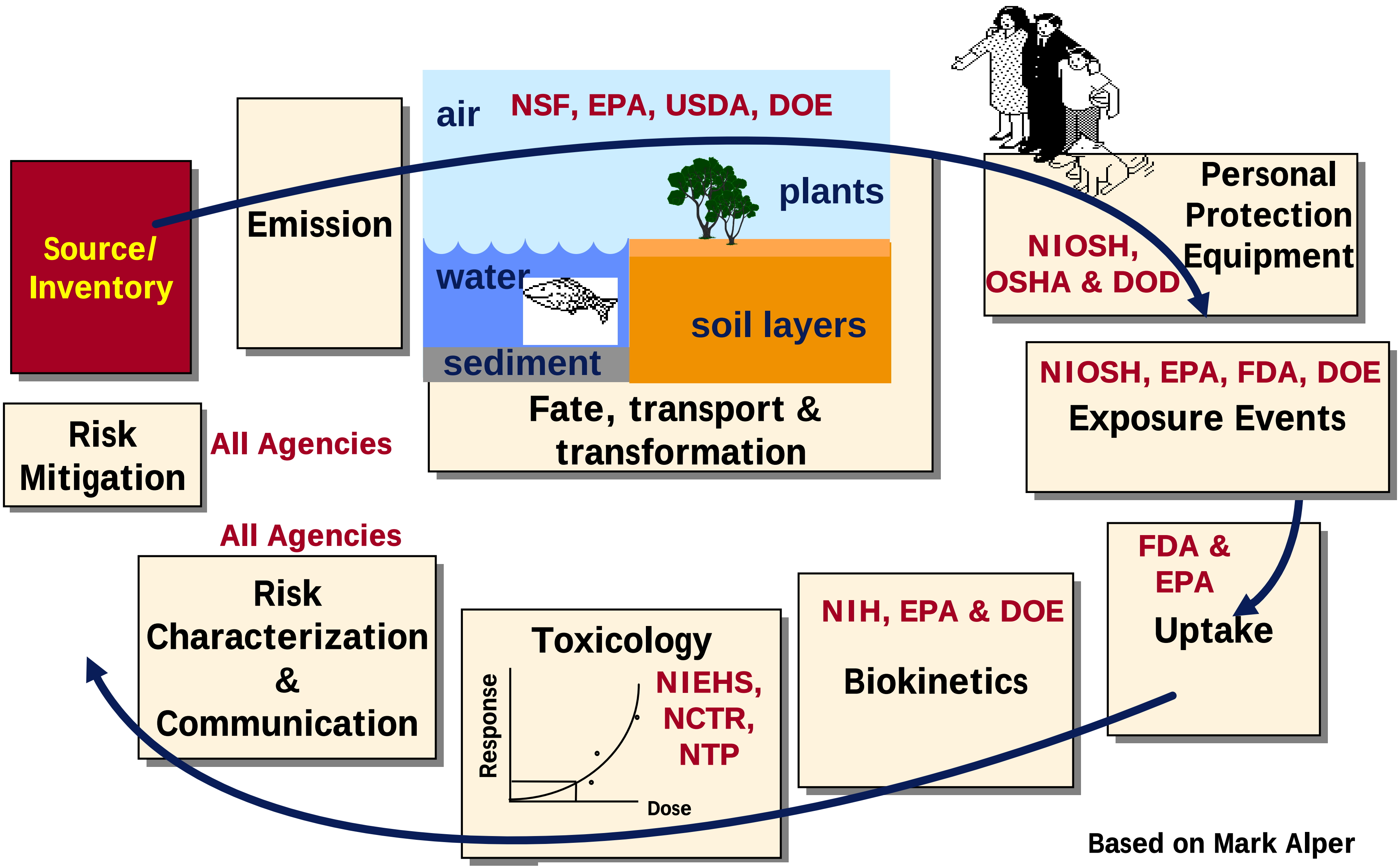
Scientific Advisory Committee On Alternative Toxicological Methods

NIEHS

NCTR
National Center for Toxicological Research
U.S. Food and Drug Administration

NIOSH

B. Regulatory and Research Topics for EHS



Based on Mark Alper

DOE Molecular Foundry—Lawrence Berkeley National Laboratory

C. Current NNI coordinated measures for EHS

- Develop statement on “Best practices” for research laboratories and industry units (NIOSH, NSF, DOE, NASA, DOD), and identify gaps
- Map of EHS responsibilities and contacts in each NNI agency
- Establish response approach to an unexpected event or an emergency
- Identify protective equipment suitable for nanoparticles and other nanostructured materials (OSHA, NIOSH, other agencies)
- Support development of instrumentation and metrology (NSF, NIST)
- Develop a unified, explicit nomenclature (agencies, ANSI)
- Develop standards for nanotechnology (NIST, ANSI, IEEE, ASME)
- Collaborative activities with industry (SRC, CCR, Phrma, IRI)
- Identify research and educational needs (Fundamental, GCs)

NSET Group: “Nanomaterials Environmental and Health Implications”

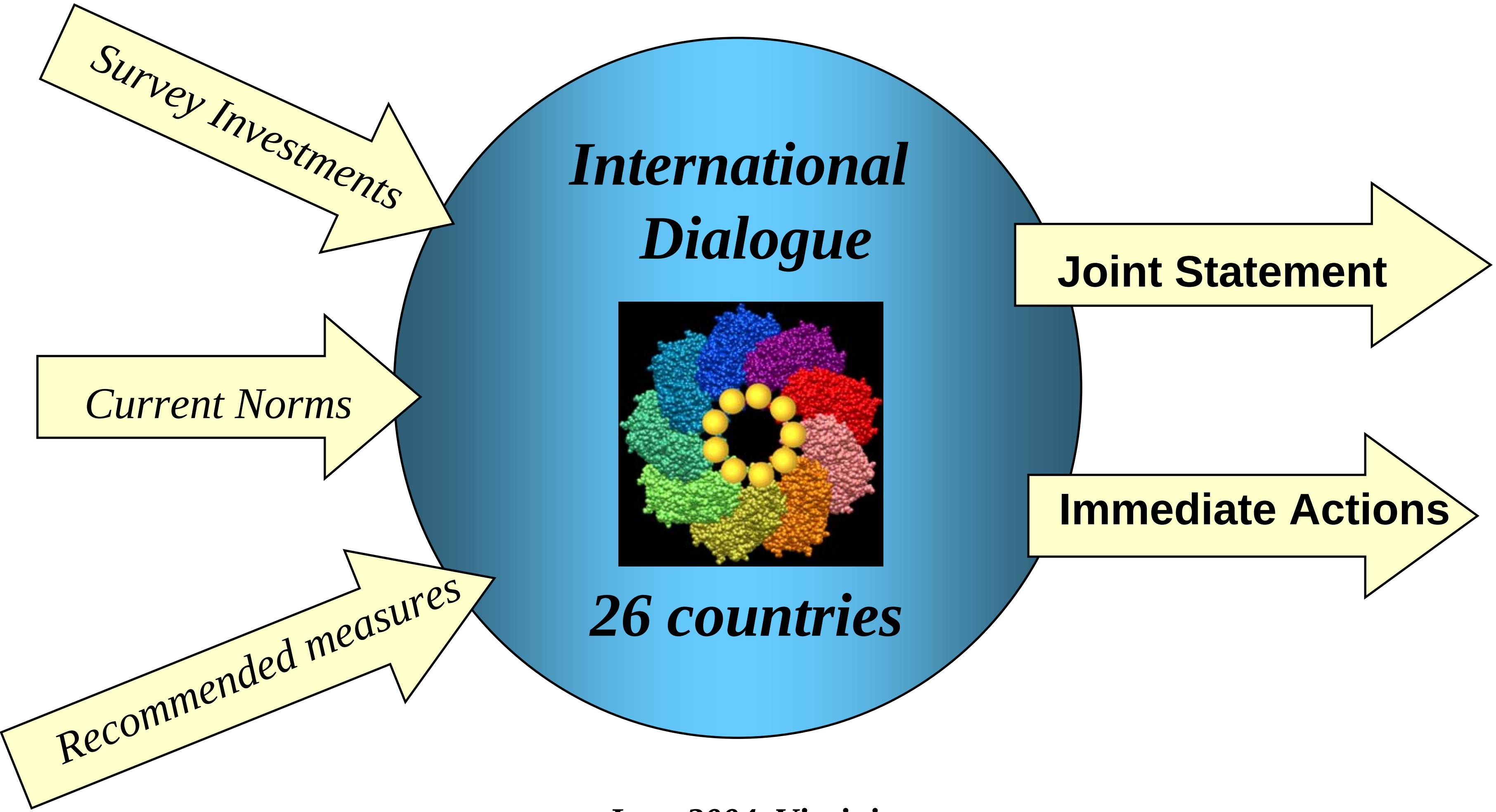
OSTP Group: “Risk Assessment of Nanotechnology” task force

D. NNI workshops on nano-environmental research

examples

- NSF, 9/2000: “Societal Implications of Nanoscience and Nanotechnology”
- NSF, 6/2002: “Nanoparticles and the environment” (grantees meeting, book)
- EPA, 11/2003: “Nanotechnology and the environment applications and implications” (grantees meeting, brochure)
- ACS, 3/2003: “Symposium on nanotechnology implications in the environment”, New Orleans
- NNI, 5/2003: “Vision for environmental implications and improvement” *(interagency, report)*
- NSET/NNCO, 8/2003: Review of Federal Regulations (report)
- NNI, 9/2003: Interagency : grantees meeting (report);
- Wilson Center, 10/2003: EPA and FDA regulatory functions (report)
- NSET, 12/03 “Societal Implications of Nanoscience and Nanotechnology (II)”

E. International Dialogue on Responsible Nanotechnology R&D



June 2004, Virginia

http://www.nsf.gov/home/crssprgm/nano/dialog.htm

After 3 years of NNI:
New R&D potential targets for 2015 (ex.)

2004 **2015**

Nanoscale visualization and simulation of 3D/m domains

= Micro domains with nano space and time resolutions

Transistor beyond/integrated CMOS under 10 nm

New catalysts for chemical manufacturing

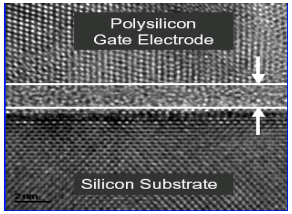
No suffering and death from cancer when treated

Control of nanoparticles in air, soils and waters

Challenge: Transistor beyond/integrated CMOS under 10 nm – 2015

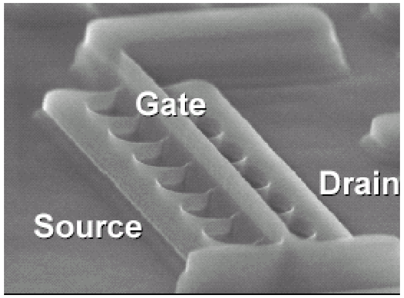
- In the 70s, 80s and 90s
  Geometrical scaling was the major driver

- In the 2003 - 2012 period (industry target)
  Use of novel physical phenomena to extend performance by equivalent scaling are the major drivers. Examples (2004):



1.2 nm gate oxide is ~5 Silicon atom layers thick

"Strained Silicon" - Separating the Silicon Atoms for Faster Electron Flow



Tri-gate Transistor

In addition, to explore beyond CMOS:
- New carriers instead of electron charge
- Integrate CMOS with other nanodevices
- New system architectures
- Integration with applications

Challenge 2015: To simulate engineering problems from basic principles at the nanoscale

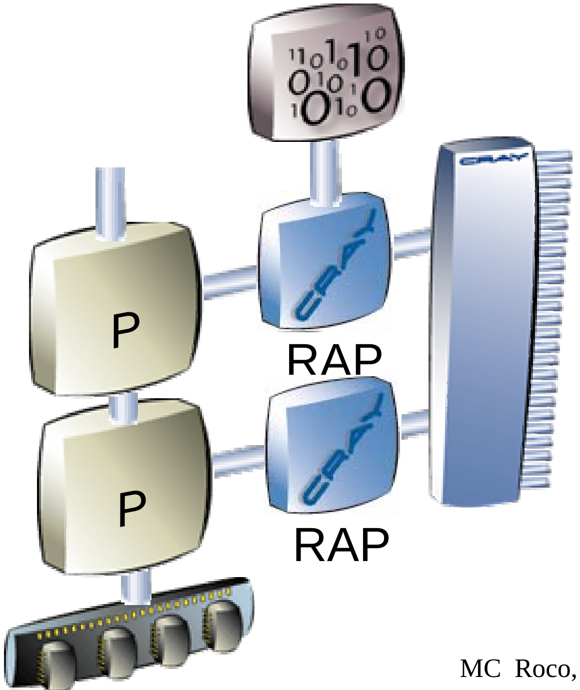
Using nanotechnology to build the highest speed processors

Using fast computers and reconfigurable computing for nanoscale S&E “application acceleration” (for 100x potential speeedup)

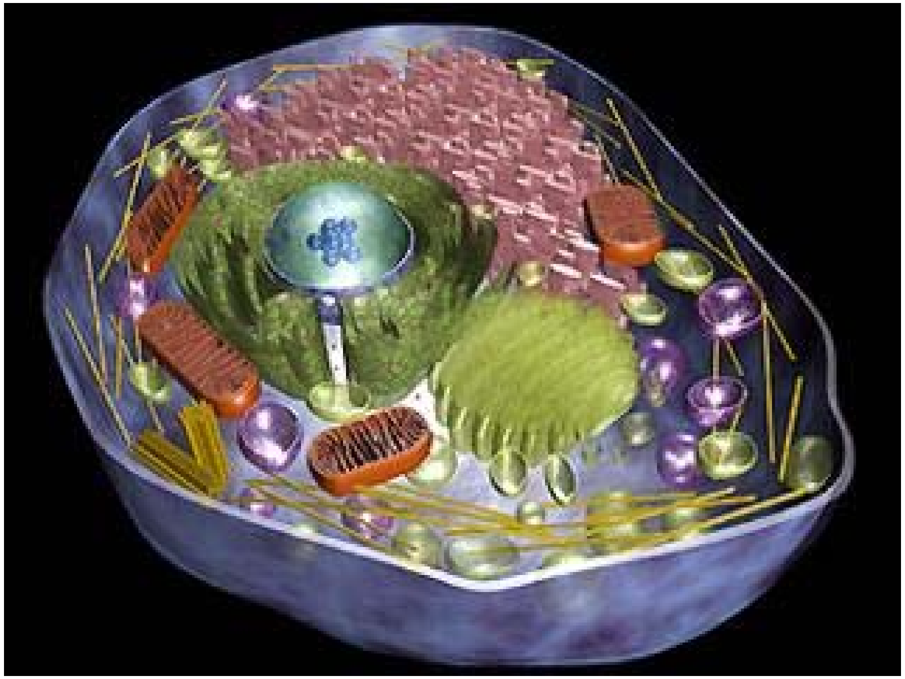
Capability 2004 (Cray X1):
50+ TFLOPS (fastest computer in the world)

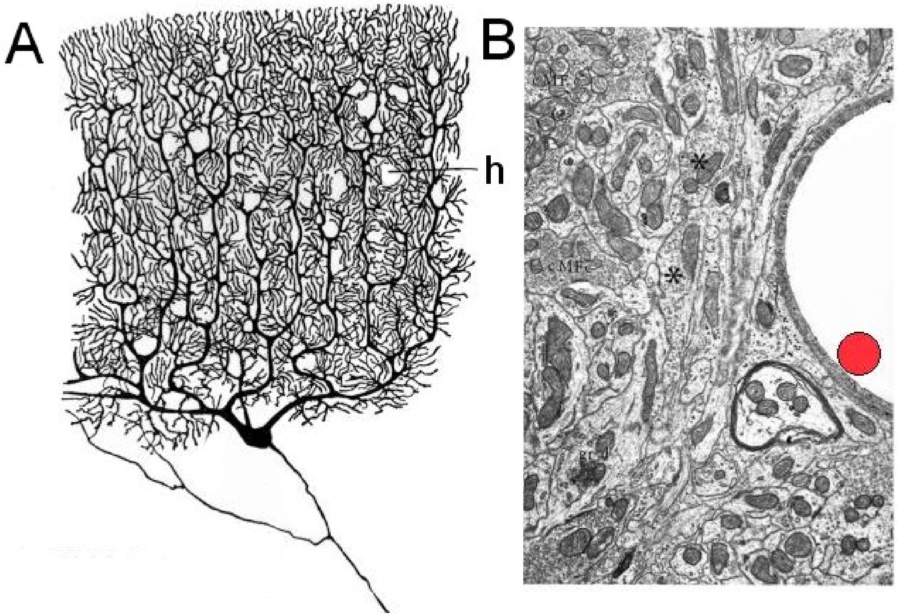
~ 2010 (Cray Cascade):
DARPA – NSF – DOE acad. support
1,000+ TFLOPS

~ 2015 (Cray target):
10-100,000 TFLOPS



Challenge 2015: Specify the state of a cell and of nervous system from the nanoscale





R. Llinas, 2003

The Cell

– the machinery of life

The brain

– system based on nanoscale processes

Measure and simulate, 3 dimensional, highly parallel, . . .

Challenge 2015: To Eliminate Suffering and Death Due to Cancer

"A Vision Not a Dream!" by using nanotechnology, A v. *Eschenbach, NCI*

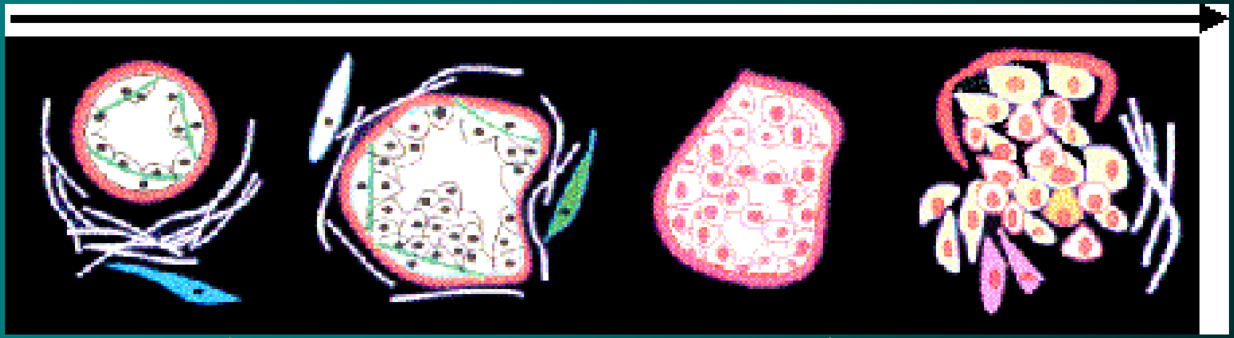
Where We Want To Be ⟵ Where We Are

Detection and Diagnosis

Detection and Diagnosis

Malignant Tumors With Metastases

Year 0 Year X Year Y Year Z



Prevention

Prevention

Cancer results from accumulation of multiple genetic changes in a cells.
Nanotechnology will allow earlier detection and prevention (Year 0)

GE Nanotechnology

Aircraft Engines

Water

Platform Technologies

NanoTubes and NanoRods

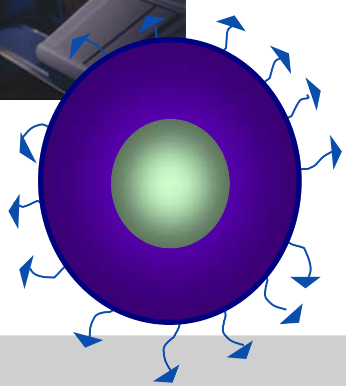
NanoParticles

NanoCeramics

NanoStructured Metal Systems

Hybrid Materials

Healthcare



Energy

After 3 years of NNI:

New R&D potential targets for 2015 (2)

2004 **2015**

Advanced materials and manu.: ½ from molecular level

Pharmaceuticals synthesis and delivery: ½ based on nano

Converging technologies from the nanoscale

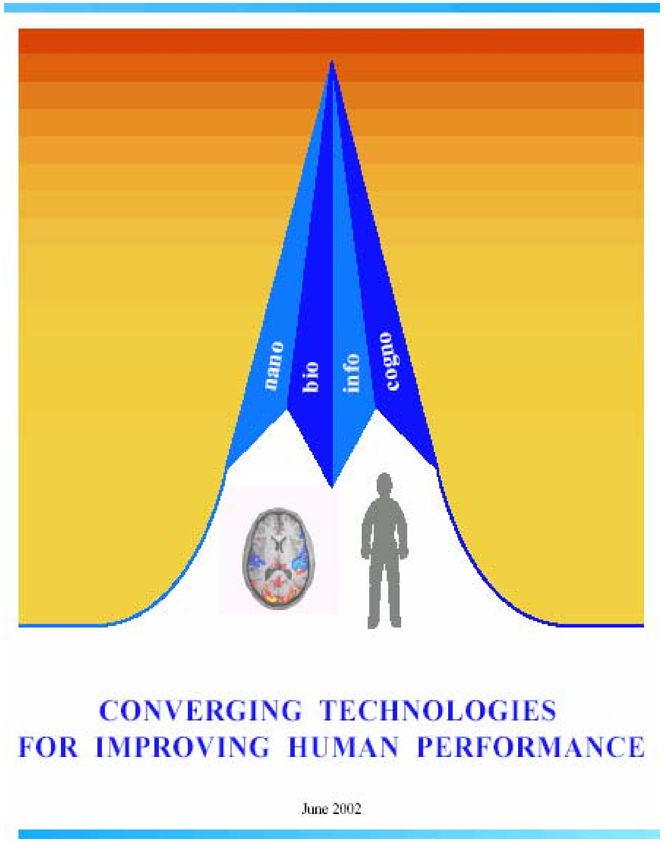
Including: artificial organs, manufacturing multidisciplinary platforms, etc.

Life-cycle biocompatible/sustainable development

Education: nanoscale instead of microscale-based

Integrating science and technology from the nanoscale (NBIC convergence)

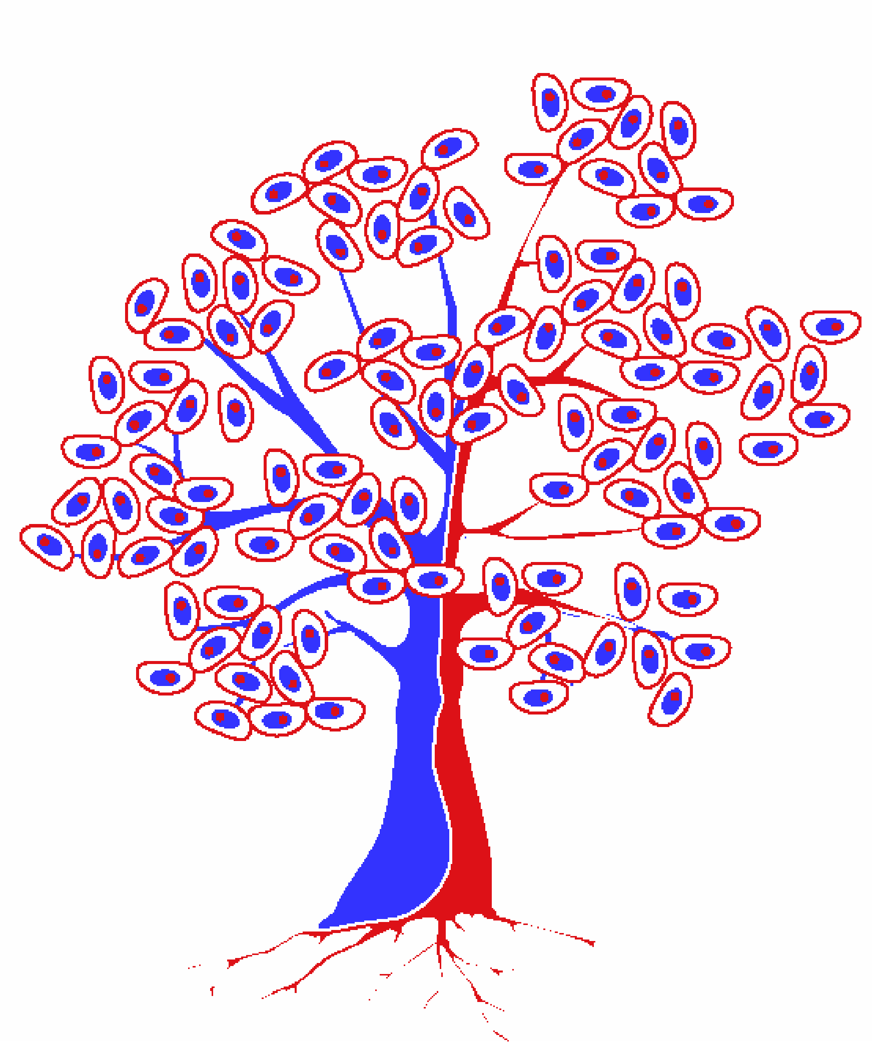
- **Broad and timely opportunity**
  - ➢ **Understanding unity in nature beyond renaissance, and technology integration from the nanoscale**
  - ➢ **Powerful transforming tools (NBIC: nano-bio-info-cogno) developing at the confluence of disciplines**
  - ➢ **Improvement of individual and group human performance becomes possible**
  - ➢ **Need for anticipation ('learning before doing') and deliberate choices**
- **NBIC - agents of accelerated, synergistic change**



(December 2001)

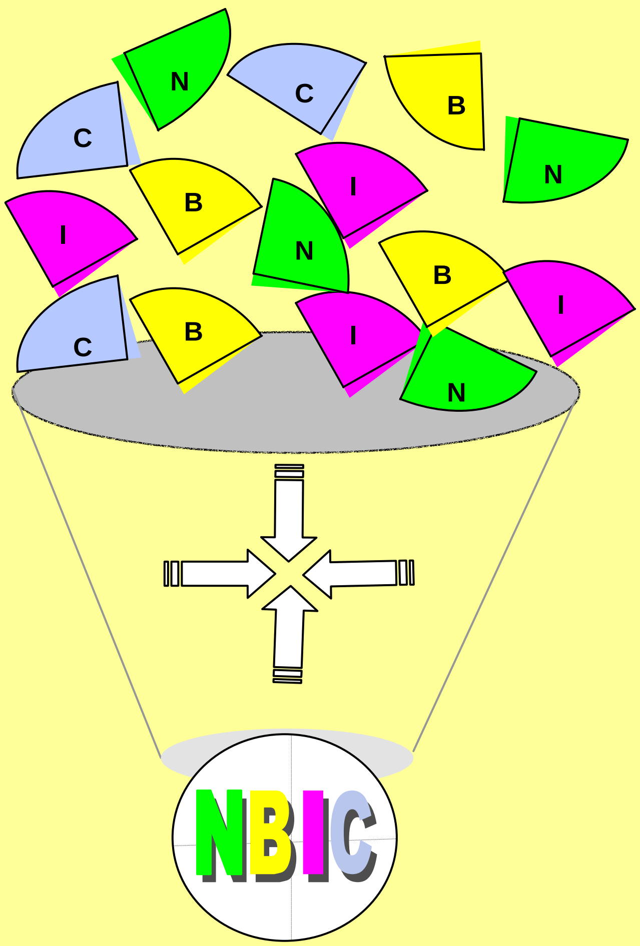
Online www.nsf.gov/nano, also Kluwer Academic Publ

Vision for 2020: Regenerative medicine (2004)



Combine precision assembly of matter (nanotechnology), building blocks of living systems (biotechnology), spatio-temporal flow of information (IT), and cognitive sciences.

Commercializing and Managing the Converging Technologies (2004)

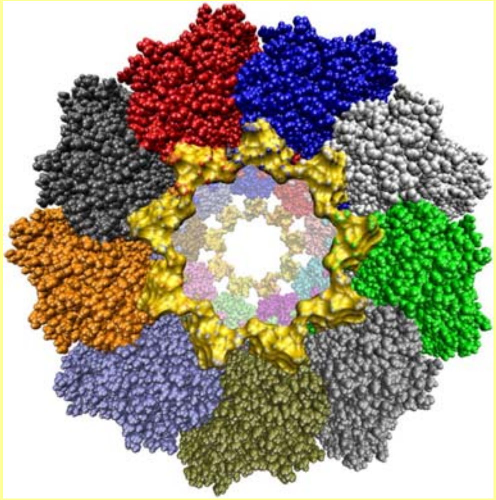


NSF sponsored workshop (September 2003) and report (April 2004)

Northwestern University, Center for Technology & Innovation Management (CTIM)

Coevolution of Human Potential and Converging New Technologies
(Feb. 2003 and Feb. 2004 meetings)

Topics:



Converging technologies
and future society

Transforming tools

Multidisciplinary education

Coevolution human potential – NBIC – business

In: Annals of the New York Academy of Sciences, Vol. 1013, 2004

Note: International perspective affected by cultural trends

Transforming and Responsible development of nanotechnology

Reaching at the building blocks of matter for manmade and living systems makes the transforming tools more powerful and the unintended consequences more important than for other technologies

Key R&D issues:

- systematic control of matter at the nanoscale
- using system approach and converging technologies
- aligning R&D goals with societal needs,
  including risk governance and public interaction

Appendix (1):
Reports from NNI Conferences/workshops

Regional workshops of NNI

"Nanotechnology: Opportunities and Challenges"
South-west region; host UCLS, September 2001,
wtec.org/nanoreports/FinalUCLAnanoRpt0302.pdf

"From the Laboratory to New Commercial Frontiers"
South-east regional; host Rice University, May 2002,
wtec.org/nanoreports/ACF64.pdf

Grand Challenge (topical) workshops

“Nanotechnology Innovation for Chemical, Biological, Radiological, and Explosive Detection and Protection”
May 2002, www.wtec.org/nanoreports/cbre/

“Chemical Industry R&D Roadmap for Nanomaterials By Design: From Fundamentals to Function”
October 2002 Vision 2020/NNI Grand Challenge Workshop,
www.chemicalvision2020.org/nanomaterialsroadmap.html

Buildings for Advanced Technology Workshop, at NIST, Jan 14-16, 2003; www.nanobuildings.com/bat/overview/default.htm

Appendix (2):
Other Grand Challenge (topical) workshops

NNI Grand Challenge (GC) Workshop on Nanomaterials, at NSF, June 11-13, 2003

NNI GC Workshop: Nanoscale Processes for Environmental Improvement, at NSF, May 8-10, 2003.

Interagency Grantees Meeting on Nanotechnology and the Environment: Applications and Implications, at NSF, September 15-16, 2003. es.epa.gov/ncer/publications/nano/index.html

NNI Workshop on NanoBiotechnology, Arlington, VA, Oct. 9-11, 2003

NNI Workshop on Societal Implications of Nanoscience and Nanotechnology, at NSF, Dec. 3-5, 2003

NNI GC Workshop on Instrumentation and Metrology for Nanotechnology, at NIST, Jan. 27-29, 2004

NNI GC Workshop on Nano-electronics, -photonics, and -magnetics, Arlington, VA, Feb. 11-13, 2004

NNI GC Workshop on Nanoscience Research for Energy Needs, Alexandria, VA, March 16-18, 2004

Appendix (3): Other Reports on Nanotechnology Sponsored by NNI Agencies, 2000 to Present

Nanoscience and Nanotechnology: Shaping Biomedical Research, Bioengineering Consortium, BECON, report from the June 2000 BECON workshop. www.becon.nih.gov/nanotechsympreport.pdf

***NNI: The Initiative and its Implementation Plan*. ** National Science and Technology Council (NSTC), Committee on Technology, Interagency Working Group on Nanoscience, Engineering and Technology (IWGN), July 2000. www.nsf.gov/home/crssprgm/nano/nni2.pdf

Societal Implications of Nanoscience and Nanotechnology. NSF Report, March 2001. www.wtec.org/loyola/nano/societalimpact/; also available in hardcover from Kluwer Academic Publishers, 2001

***WTEC Panel Report on Tissue Engineering,* WTEC, Inc., January 2002. Sponsored by NSF, NIH, DARPA, NIST, and FDA; www.wtec.org/loyola/te/final/; also Academic Press**

***Theory and Modeling in Nanoscience*.** Report of the May 10–11, 2002, Workshop BES/DOE www.sc.doe.gov/bes/Theory_and_Modeling_in_Nanoscience.pdf

Appendix (4): Other Reports on Nanotechnology Sponsored by NNI Agencies, 2000 to Present

Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science. June 2002, NSF/DOC-sponsored report. www.wtec.org/ConvergingTechnologies/; also Kluwer, 2003

***Report of the Nanogeoscience Workshop*, Berkeley, CA, June 14-16, 2002,** Sponsored by NSF. http://www.nsf.gov/home/crssprgm/nano/geo_workshop.pdf

***Nanotechnology and the Environment: Applications and Implications*. EPA Nanotechnology Grantees Workshop,** August 29, 2002. www.nsf.gov/home/crssprgm/nano/GC_ENV_EPA2002_Proc_03-0204.pdf

***Research Directions and Nanoscale Science Research Centers*, DOE/BES, February 2003,** www.sc.doe.gov/bes/NSET_NSRC_brochure_FEB03.pdf

***Nanoscale Science and Engineering for Agriculture and Food Systems*. Report from the National Planning Workshop, Washington, DC, Nov. 18-19, 2002.** www.nseafs.cornell.edu/web.roadmap.pdf

***Emerging Issues in Nanoparticle Aerosol Science and Technology*, National Science Foundation Report, January 2004.** www.nano.gov/html/res/NSFAerosolParteport.pdf

Appendix (5): Other Reports on Nanotechnology Sponsored by NNI Agencies, 2000 to Present

- ***National Nanotechnology Initiative; R&D Supporting the Next Industrial Revolution:*** *Supplement to the President's FY 2004 Budget*, National Science and Technology Council (NSTC), Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology (NSET), Oct. 2003. www.nano.gov/html/res/nni04_budget_supplement.pdf
- ***Small Wonders, Endless Frontiers: Review of the National Nanotechnology Initiative*. NRC, June 2002.** www.nano.gov/html/res/smallwonder.html

Updates information on :

www.nano.gov

www.nsf.gov/nano